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FINAL REPORT  
CLOSEOUT/(N00014-76-C-0274 and N00014-85-C-0230)  
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Under this contract we have completed 28 projects that are summarized in the following publications. Except for those represented by the enclosed reprints, all the projects have been described in periodic progress reports to the project officer at the Office of Naval Research, Dr. Edward Green. A summary of our most recent progress follows the list of publications.

PUBLICATIONS (peer reviewed)

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- Minas, H.J., M. Minas and T.T. Packard. Productivity in upwelling areas deduced from hydrographic and chemical fields. *Limnology and Oceanography*, 31(6):1182-1206 (1986)
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#### TECHNICAL and DATA REPORTS

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Statement A per telecon Edward Green  
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## RESEARCH SUMMARIES

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### Formation of the Alboran Oxygen Minimum Zone

The enhanced oxygen minimum in the western Alboran Sea is the result of a chain of processes starting with nutrient injection into the inflowing Atlantic water at the Strait of Gibraltar. These nutrients originate in the outflowing Levantine Intermediate Water, outflowing Mediterranean deep water, and inflowing North Atlantic Central Water (from 200 m). They are injected into the inflowing Atlantic surface water by strong mixing at the eastern end of the Strait. They move with Atlantic surface waters along the Spanish coast, mix with nutrients upwelling in the northwestern Alboran Sea and stimulate phytoplankton productivity. The organic matter produced by this mechanism is transported both with the anticyclonically flowing waters of the Alboran gyre and with the waters that converge at the center of the gyre. Sedimentation in this convergence zone helps to deliver this organic matter to the Levantine Intermediate Water where bacteria metabolize it to CO<sub>2</sub> at the expense of the existing oxygen. This mechanism develops the most intense oxygen minimum zone in the Mediterranean Sea.

### Deep-Sea CO<sub>2</sub> Production

A biochemical mechanism that could cause changes in the atmospheric CO<sub>2</sub> is the change in the deep-sea CO<sub>2</sub> production rate, or in other words, the deep-sea metabolic rate. This is the rate at which the deep-sea community of organisms degrades organic carbon and generates carbon dioxide. How much must this process be changed for the ocean to sequester a significant fraction of the new CO<sub>2</sub> that is annually appearing in the atmosphere? To answer this question the amount of CO<sub>2</sub> vented to the atmosphere and the amount injected into the deep sea via metabolism must be known. Sediment traps provide one way of assessing this rate. Calculating it from an understanding of the way CO<sub>2</sub> is produced during the degradation of organic matter is another way. Recently this approach has yielded some interesting results. From respiratory electron transport system measurements made in the Sargasso Sea and in the central tropical Pacific the CO<sub>2</sub>

production rates for the Atlantic and the Pacific have been calculated. These calculations showed that if the deep-sea metabolic  $\text{CO}_2$  production rate increased by only 15% it would cause an additional 1 gigaton (Gt) carbon per year to be sequestered in the deep sea. Since the amount of carbon that can not be accounted for by existing global carbon budgets is of the order of 2 Gt per year, the 15% increase in deep-sea metabolism that we calculated above would be significant (Packard *et al.*, 1988).

#### Peru Current Oxygen Minimum Zone Studies

We have recently discovered a potential couple between El Nino events in the Pacific Ocean and the rate at which  $\text{CO}_2$  and  $\text{N}_2\text{O}$  are absorbed and released by the ocean. Between El Nino events, cold deep water in the eastern Pacific ocean rises close to the sea surface and brings nutrients that stimulate plankton growth. This enhanced productivity has two effects on the green house gases. First, it increases the rate at which  $\text{CO}_2$  is removed from the atmosphere and the rate at which it is transported, in the form of particulate organic matter, to the deep-sea. Second, this enhanced productivity leads to additional organic matter in the sub-surface waters which stimulates denitrification, consumes  $\text{N}_2\text{O}$ , and thus leaves less to be vented to the atmosphere.

#### New Production in the World Ocean

Deep-ocean respiration, in terms of  $\text{CO}_2$  production, was calculated from measurements of the respiratory electron transport system in microplankton samples from the north central Pacific Ocean and from the northeastern Sargasso Sea. These calculations support recent arguments that the Pacific Ocean supports more phytoplankton productivity in its surface waters than does the Atlantic. However, more importantly, these measurements facilitate the calculation of new production because the new production of the phytoplankton must balance the respiration ( $\text{CO}_2$  production) of all of the deep-sea organisms below the surface layer. When this calculation was made the result was 21.9 Gt C per year, 4 to 11 times greater than previous calculations, but very close to a recent computation made from satellite color scanning data and a separate computation made from a global integration of carbon productivity data.

#### Phytoplankton Ecology

The results of a collaborative project with Quay Dortch of

LUMCOM suggest that the trophic pyramids of oligotrophic and eutrophic plankton ecosystems are the inverse of one another. Before our study it was thought that a normal trophic pyramid, with most living biomass comprised of plants, represented all marine ecosystems. However, oligotrophic and eutrophic environments differ markedly in phytoplankton biomass, but, due to difficulties sampling and quantifying the small, non-plant organisms, it has been difficult to determine the relative plant and non-plant biomass. We calculated the chlorophyll a /protein ratio (Chl/Pr) of oceanic particulate matter from our very extensive suites of field data. This ratio serves as an index of phytoplankton (plant) biomass to total biomass. We found that in eutrophic areas with high chlorophyll concentrations, the Chl/Pr ratio approaches that of pure phytoplankton cultures, suggesting that phytoplankton constitute most of the biomass. In contrast, the Chl/Pr ratio from oligotrophic areas is low, indicating that most of the biomass consists of bacteria and zooplankton and that in these areas an inverted biomass pyramid better describes the system. Thus, ecosystem structure must be fundamentally different between eutrophic and oligotrophic areas.